Circle and "J" Hook Pilot Study in Maryland's Recreational Shark Fishery
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Introduction
Although circle hooks have been around for a long time, their use as a conservation measure did not start gaining momentum until the late 1990's (Straughn, Unknown). Since that time, voluntary and mandatory usage of circle hooks has rapidly expanded into many fisheries. There are numerous studies of recreational use of circle hooks in teleost fisheries as well as commercial studies on sharks from the Pelagic Long Line fishery (PLL; Serafy et al., 2011; Lucy et al., 2002; Cook and Suski, 2004; Diaz, 2008; Watson et al., 2005; Skomal et al., 2002; Kaplan et al., 2007; Graves and Horodysky, 2008). The weight of evidence suggests that fewer fish are deep hooked and catch efficiency is equal to or better than J hooks. This research has helped circle hooks gain acceptance and supported regulatory requirements for their use in some fisheries and tournaments (Cook and Suski 2004; Straughn, Unknown; Graves and Horodysky, 2008).

Some anglers have been reluctant to switch to circle hooks because of catch efficiency concerns and doubts about study results' applicability in the shark fishery (Prince et al., 2002). Previous conclusions from teleost recreational studies may not apply to sharks due to differences in anatomy and behavior (Cook and Suski, 2004; Serafy et al., 2011; Lucifora et al., 2009; Hammerschlag et al., 2011). Furthermore, results from PLL studies may not translate well into the recreational fishery due to differences in methodology such as gear and bait. Despite the abundance of circle hook studies in teleost fisheries and commercial shark fisheries, there are no published studies and only one symposium poster presentation for circle hooks in the recreational shark fishery (Hammerschlag et al., 2011). Scientific evidence supporting the benefits of circle hooks is needed to convince recreational shark anglers to voluntarily switch hook types and to support regulatory measures requiring circle hook use (Prince et al., 2002; Skomal et al., 2002; Graves and Horodysky, 2008).

The recreational shark fishery has a large release component resulting from angler preference, regulations, and tournament rules. In Maryland, sharks are targeted by tournament and non-tournament anglers from May into October. In addition to tournament favorites such as Mako (*Isurus oxyrinchus)*, Thresher (*Alopias vulpinus)*, and Blue (*Prionace glauca)* sharks there are three prohibited species that are commonly caught: Sandbar (*Carcharhinus plumbeus)*, Dusky (*Carcharhinus obscurus)*, and Sand Tiger (*Carcharias taurus)* sharks. The federal HMS 2013 Recreational Compliance Guide requires prohibited species to be released in a manner that maximizes the probability of survival, without removing the fish from the water. The Atlantic States Marine Fisheries Commission (ASMFC) Interstate Fishery Management Plan for Atlantic Coastal Sharks (2008) includes the goal to promote complementary management in state and federal waters.

If circle hooks reduce deep hooking in the recreational shark fishery, they could benefit shark populations by lowering catch-and-release fishing mortality. If circle hooks lower catch-and-release fishing mortality in sharks, then it would be beneficial to expand their use in the recreational shark fishery. The potential benefits of circle hooks to sharks notwithstanding, many recreational shark anglers may only be persuaded to switch tackle if they can first be persuaded that circle hooks maintain or improve catch efficiency.

The goal of this pilot study was to obtain evidence concerning the differential action of circle hooks and traditional J hooks in Maryland's recreational nearshore and offshore fisheries. In addition, this pilot study provided information on the sample size needed to determine statistical significance. Consistent fishing practices were encouraged (such as bait type, bait species, tackle, and presentation) in order to minimize sample sizes (Diaz 2008).

Specifically, this study was designed to answer the following questions:
1. What sample sizes are necessary to determine differential action of hook types?
2. Is the hooking outcome (landed versus lost) different between hook types?
3. Is the frequency of deep hooking different between hook types?
4. Is catch rate different between hook types?

Methods

Field Methods
Captain Mark Sampson chartered and fished as he normally did with the exception of dedicating two surface lines to this study while on dedicated shark trips. Fishing was conducted from either a drifting or anchored boat. Chum was used to attract sharks to the area. Baited lines attached to conventional sport fishing rods and reels were used to hook and land the sharks. Study lines were attached to floats and fished at the surface (< 2 m). The captain or mate attempted to set the hook when using a J hook and the rod was left alone for self hooking when circle hooks were used. However, if a shark continued to swim towards the boat after taking a bait, the rod was left in the rod holder and the reel was cranked to tighten the line and allowed the hook to set. Once the shark was hooked on either hook, the angler then took the rod from the rod holder.

Study lines were identical to each other and were rigged either with circle hooks or a comparably sized J hook. Both lines were switched to the other type of hook after every bite. Circle hooks were limited to Mustad model 39960D hooks in sizes 16/0 and 13/0 (Mustad 2011). The 16/0 hooks were used when fishing offshore where larger sharks were anticipated and larger baits are typical. When fishing nearshore and using smaller baits for smaller sharks, 13/0 circle hooks were used. J hooks were limited to Mustad model 7731D hooks in sizes 9/0 and 6/0. The 9/0 J hooks were used when fishing offshore where larger sharks were anticipated and larger baits are typical. When fishing nearshore and using smaller baits for smaller sharks, 6/0 J hooks were used.

Bait type was allowed to change daily as needed, however, it was required to be identical in size and species on both lines at the same time. Baits were refreshed at the same time. The species of the bait and whether or not it was frozen or fresh were recorded on the datasheet.

The outcome of each shark strike was recorded as bite, lost, or landed similar to Skomal et al. (2002, Figure 1). A "Bite" was defined as a strike that resulted in the fish not being hooked. The captain or mate would make the determination either by looking over the remaining bait for teeth marks or by visually observing the shark. The event was not recorded if the captain or mate could not confirm that it was a shark bite. "Lost" was defined as a hooked fish that became unhooked before the mate could grab the leader. "Landed" was indicated on the datasheet when

the shark was fully played to the boat. Fight time was recorded in minutes and began when the angler grabbed the rod and ended when the mate had the leader at the side of the boat.

The captain or mate completed the datasheet only for sharks that interacted with the study lines. Once the shark was landed, the captain determined if it was to be boated or kept in the water next to the boat for workup. Species, hook type, size, location, and length were recorded on the datasheet. Hook location was recorded as "Jaw", "Throat", "Gut", and "Foul". "Deep hooking" was defined as landed sharks that were hooked in the throat or gut. Hooks were removed using a dehooker or had the line cut; the captain or mate selected the appropriate method that provided the shark the maximum likelihood of survival. Boated sharks were measured for total and fork lengths in inches using a fiberglass measuring mat placed on the floor. Lengths were estimated for sharks that were not boated. Weights were estimated and sex was determined for most landed sharks. Additional variables were Location, Latitude, Longitude, Start and End times, Boat Disposition (Anchored or Drifting), and Condition/Comments. Datasheets were periodically collected for data entry by MDNR.

Statistical methods
Analysis stratified the study sites into nearshore and offshore zones because of differences in species composition and tackle requirements. Nearshore was defined as waters from the beach to 20 miles and offshore was defined as waters 20 or more miles from the beach. Most of the nearshore fishing occurred from one to six miles from the beach and the majority of offshore fishing took place between 20 and 30 miles from the beach. All fishing trips left from Ocean City, Maryland.

Chi square theory was used to determine the minimum sample size necessary to determine statistical difference in hook performance and hooking location. The empirical (observed) distributions were used to develop "expected" percent frequency distributions. These percentage distributions were expanded to absolute frequency distributions with a minimum of five observations in each cell, consistent with chi square requirements. The minimum sample size needed to support chi square analysis was calculated as the sum of frequencies in all cells.

Chi Square analysis was performed on data for which minimum sample size requirements were met to determine whether hooking outcome and hooking location were independent of hook type (Skomal et al., 2002).

Two tests were used to determine the effect of hook type on catch rate. Student's t-test was used to compare catch rate between hook types, defined as sharks/trip. Regression analysis using a Generalized Linear Mixed Model (GLMM) was used to estimate catch rate and determine the effect of hook type (Prince et al., 2002).

Results

The 2013 data represented 65 charter trips targeting sharks offshore (7 trips) and nearshore (58 trips) from May through September. During those trips, 158 sharks representing seven shark species were captured on the lines dedicated to this study (Table 1). Dusky Sharks (60 sharks),

Spinner Sharks (34 sharks), Atlantic Sharpnose Sharks (29 sharks), and Sandbar Sharks (26 sharks) were the most commonly encountered species.

A total of 213 interactions with the study rods occurred. This was lower than the 2012 sample size and some analyses had to be conducted on combined 2012-2013 data. A chi square test indicated that the offshore and nearshore data were not statistically different and therefore it was appropriate to pool those data (p = 0.167). In 2013, 74% of hooking outcomes were Landings, 20% were Bites and 6% were Losses (Table 2, Figure 2). Sharks were landed 65% of the time with a circle hook versus 35% of the time with a J hook.   Losses (sharks hooked but not reeled to the boat) were 33% on circle hooks versus 67% on J hooks.   Both 2013 data and combined 2012/2013 data showed circle hooks were more effective than J hooks at landing a shark (both p < 0.001).

In 2013, 96% of landed sharks were hooked in the jaw (Table 3). The small 2013 sample size did not support differential analysis of hooking location, so data from 2012 and 2013 were combined. Out of 451 hooking incidents (excludes foul hooked), significantly fewer deep hooked sharks were caught on circle hooks than on J hooks (4% vs. 14%, p < 0.001).

Student's t-test did not show a significant difference between catch rates by hook type using the 2013 data (1.70 sharks/trip/hook type, p = 0.28) but the circle hook catch rate was significantly higher for 2012/2013 combined data (2.06 vs. 1.64, p = 0.006).

Regression analysis indicated the effect of area (inshore vs. offshore), shark species, bait type, bait species and boat disposition on 2013 data did not show any variable to have a significant effect, but combined 2012/2013 data showed a highly significant effect by hook type (p = 0.004). No other factor was significant (all p > 0.30).

Discussion
The 2013 data did not update our understanding of sample size because fewer sharks were caught than recommended in 2012. Combining two years of data for analyses allowed us to obtain answers to the questions of this study.   This pilot study has shown that significant effects and differences exist between circle and J hooks, but that this study's methodology does not collect sufficient samples to demonstrate these on an annual basis. Either the data must be pooled across years or a larger collection effort is needed to obtain definitive results within a single season. The results of this dependent study can be used to support an independent verification of these results.

Coastal sharks (Dusky, Spinner, Sandbar, Atlantic Sharpnose, Blacktip Sharks, and Tiger Sharks) were encountered more in this study than pelagic sharks (Blue) because there were very few offshore trips. The offshore sample size may have been affected by the short offshore shark season, which typically lasts from early May to the end of June, and weather. Maryland experienced a cool spring which kept water and air temperatures cooler than normal and that may have influenced shark migrations and feeding behaviour. June 2013 had several bad weather days that prevented offshore fishing. Additionally, due to the distance traveled to get offshore there was also no chance of multiple trips per day, which is possible when fishing nearshore.

The 2013 species compositon was different from 2012. Noticably missing from the 2013 data were Shortfin Mako Sharks and Thresher Sharks. One Blue Shark was atypical for that time of year as well as the absence of Scalloped and Smooth Hammerheads. The changes to the species composition may also be related to the atypical weather patterns previously mentioned.

The data clearly showed that circle hooks outperform J hooks in hooking outcome. There were fewer bites without landings reported on circle hooks as well as a higher proportion of landed sharks. The lower proportion of sharks lost on circle hooks may be a result of the difference in setting technique used for the hook type and hook design (Prince et al., 2002; Cook and Suski, 2004). With circle hooks the shark hooks itself rather than the angler setting the hook as with J hooks.

Overall few sharks were deep hooked in this study and circle hook landings had fewer occurrences of deep hooking than J hooks. The combined 2012-2013 data showed that circle hooks were more effective at hooking a shark in the jaw, consistent with results of many teleost studies (Prince et al., 2002, Skomal et al., 2002, Cooke and Susky, 2004; Rudershausen et al, 2011).

These data indicate that hook type is a driving factor in shark fishing success. Both the difference in catch rate and the significant effect of hook type indicate that circle hooks improve fishing success for some species of sharks.

Minimizing shark release mortality is important to the stock recovery for several prohibited shark species including Dusky Sharks and Sandbar Sharks. Additionally, it could also improve the populations of sharks that are not prohibited and are often released because they are undersized or undesirable. Results from two years of this study indicate usage of circle hooks for sharking could improve adherence to the federal HMS Recreational Compliance Guide (2013) that requires prohibited species to be released in a manner that maximizes the probability of survival.

Recommendations
- Continue this survey for 2014 utilizing the same basic methodology. Captain Sampson could add one additional rod or take more trips to increase the sample size.
- Discuss options with Captain Sampson about dedicating two deep lines to this survey rather than surface lines for a 2015 survey. Deep lines would offer the ability to evaluate the effectiveness of circle hooks on different species of sharks, such as Sand Tiger Sharks (*Carcharias taurus*).
- Provide results to researchers interested in conducting an independent study.

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Table 1. Species list of landed sharks captured during the 2013 Circle and J Hook Pilot Hook Study, n=158. Species are listed by total number landed.

Common Name (*Scientific Name*)	Total
Dusky Shark (*Carcharhinus obscurus*)	60
Spinner Shark (*Carcharhinus brevipinna*)	34
Atlantic Sharpnose (*Rhizoprionodon terraenovae*)	29
Sandbar Shark (*Carcharhinus plumbeus*)	26
Blacktip Shark (*Carcharhinus limbatus*)	6
Tiger Shark (*Galeocerdo cuvier*)	2
Blue Shark (*Prionace glauca*)	1
Total	158

Table 2. Circle and J Hook Pilot Study hook type status interactions, n=213.

Hook Type	Status			Total
	Bite	Land	Lost	
Circle Hook	16	102	4	124
J Hook	27	56	8	91
Total	43	158	12	213

Table 3. Circle and J Hook Pilot Study hook location by hook type, n=157. Note that one J hook landing was excluded because the hook location was not recorded.

Hook Type	Hook Location				Total
	Foul	Jaw	Throat	Gut	
Circle Hook	0	99	0	3	102
J Hook	2	52	0	1	55
Grand Total	2	151	0	4	157

Table 4. Circle and J Hook Pilot Study 2012-2013 hook location by hook type, n=461. Note that one J hook landing was excluded because the hook location was not recorded. Additionally, one circle hook entanglement was not included.

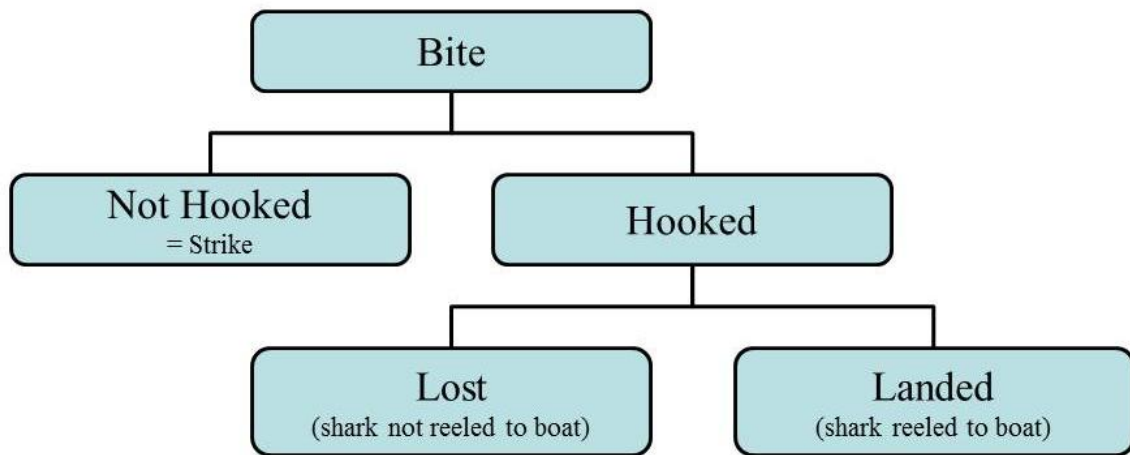| Hook Type	Hook Location				Total
	Foul	Jaw	Throat	Gut	
Circle Hook	4	267	4	7	283
J Hook	6	149	13	11	179
Grand Total	10	416	17	18	461

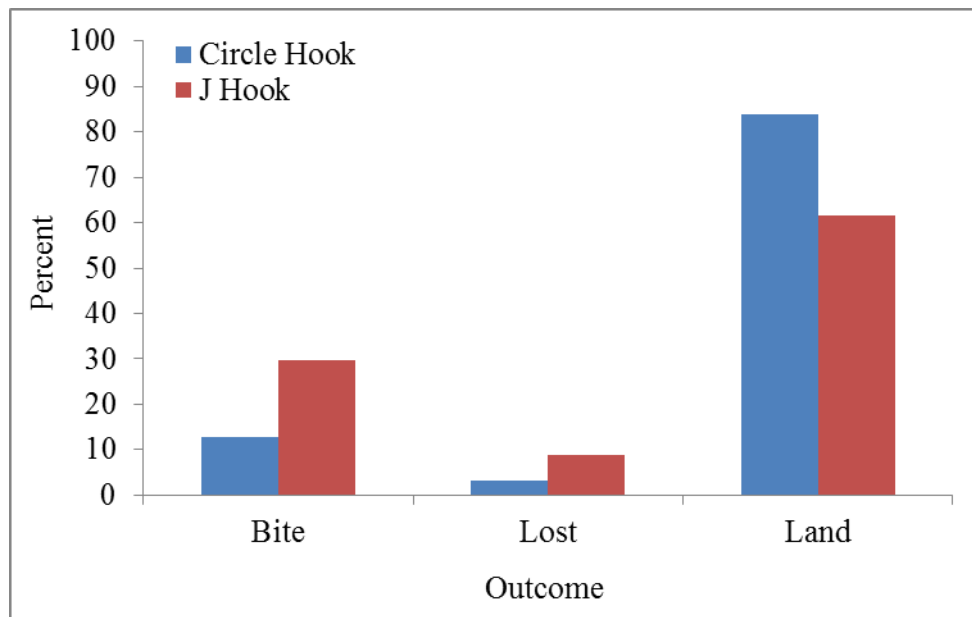**Figure 1. Strike outcome flow chart.**

Figure 2. Percentage of bites, losses, and landed sharks by hook type in 2013, n=213.